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Adams,
J. C.

RETENTION OF RECREATION RELATED POLLUTANTS IN MOUNTAIN STREAM SEDIMENTS

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Retention of Recreation Related Pollutants In Mountain Stream Sediments

Prepared by John C. Adams

University of Wyoming

Division of Microbiology and Veterinary Medicine

Laramie, Wyoming 82071

Abstract

The numbers of fecal coliforms in sediments of the streams in a high mountain watershed were generally quite low. Fecal coliforms and fecal streptococci were found to be localized in certain areas of the sediments in these streams. Snow melt and increased streamflow appeared to move the fecal coliforms through or to change the location of the fecal coliforms in the watershed. During periods of reducing streamflow there appeared to be increasing concentrations of fecal coliforms at those sample sites with low levels of these organisms in the sediments. In contrast, at two locations with higher numbers of fecal coliforms initially a reduction in numbers with time took place. Fecal streptococci in the sediments were less numerous in September than they were in July. Sediment disruption was correlated to increased numbers of fecal coliforms and fecal streptococci in water only in certain circumstances.

Introduction

Hays (3) reviewed the microbiology and chemistry of sediments of various bodies of water. He stated that total bacterial counts in ocean sediment may vary from $2x10^3$ to $1x10^5$ cells per gm depending upon location. Additionally, he said that total counts in the sediments of fresh water lakes may be very low. Okutani, Okaichi and Kitada (8) found that bacterial populations could range from $1.3x10^4$ to $2.4x10^7$ cells per gram in different locations of the Hiuchi-nada in Japan.

The numbers of certain bacteria in sediments may change during different times of the year. This is evidenced by the study of Lighthart (5) which found that sulfate reducing bacteria numbered $1x10^4$ cells per gm dry wt. in January and then they increased to $1.1x10^5$ cells per gm dry wt. in May in the sediment of the San Vicente reservoir in California.

Apparently certain bacteria tend to concentrate in sediments. Hendricks (4) and Van Donsel and Geldreich (14) found higher numbers of salmonella in the sediments of streams than they did in the overlying water. Additionally, Van Donsel and Geldreich (14) discovered that the total coliforms, fecal coliforms and fecal streptococci were 100 to 1,000 times more numerous in the mud of a stream than they were in the water above the mud. Further, Grimes (2) studies the effects of dredging upon the numbers of fecal coliforms in the waters of the Mississippi river. He discovered that the numbers of these organisms were much higher right after dredging of the river than they were before dredging occurred. He thouhgt that the reason for this was the resuspension of the bacteria from the sediments into the water column by the dredging process.

Skinner and Adams (12) showed that a failure in the waste treatment facility of a ski area resulted in the pollution of a receiving stream. This pollution continued as long as the ski area was in operation. Once the ski area closed for the season the pollution rapidly disappeared from the water. Other than the ceasing of pollution a possibility for explaining this result is that the cells adsorbed to the sediments of the stream. Another explanation might be that the cells were damaged and could not be recovered. The phenomenon of damaged cells has been documented by the work of Lin (6), Rose, Geldreich and Litsky (9), and Stuart, McFeters and Schillinger (13).

The release of adsorbed bacteria from sediment might be an important factor in the pollution of overlying waters. Seyfried and Own (11) have stated that the methodology for the bacteriological analysis of sediments is just beginning to be developed. Scheraga, Meskill and Litchfield (10) studied methods which aided the release of bacteria from marine sediments. These factors could be important in enumeration procedures and in natural release. Sterile sediments were inoculated with known bacteria and time was allowed for adsorption of the bacteria onto the sediments. The inoculated sediments were then diluted and the organisms were enumerated. Dilution series were done in conjunction with desorption studies employing acidic, neutral and basic surface active agents; acid and basic pH treatments; osmotic shock techinques and peptone water. One hundred thousandth percent cetyl trimethyl ammonium bromide in the initial dilution blank gave the best recovery of the test organisms.

Another way besides adsorption to sediments that indicator bacteria may accumulate in streams or stream bottoms is that they may grow in the environment. McFeters, Stuart and Olson (7) found relatively high numbers

(200-400 cells per 100 ml) of coliform bacteria in an unpolluted mountain stream in Grand Teton National Park during mid to late summer. This phenomenon occurred at the same time as an algal bloom. In laboratory studies these workers demonstrated that total and fecal coliforms could double or triple in numbers when grown at 13 C in the spent culture medium used to grow an isolate of Chlorella sp. obtained from the mountain stream. Water temperature in the mountain stream got at least as warm as 13 C. Further, analysis of microbial mats that attached to plexiglass plates placed in the stream for 2 weeks yielded an average of 8.4×10^4 coliforms per M^2. These workers then suggested that the growth of indicator bacteria in mats of microbial growth in mountain streams might be an important source of these microorganisms in the flowing water.

This study was undertaken to determine what role stream sediments might play in the storing and releasing of primarily fecal coliforms and secondarily of fecal streptococci in mountain streams affected by recreation and other uses.

Material and Methods

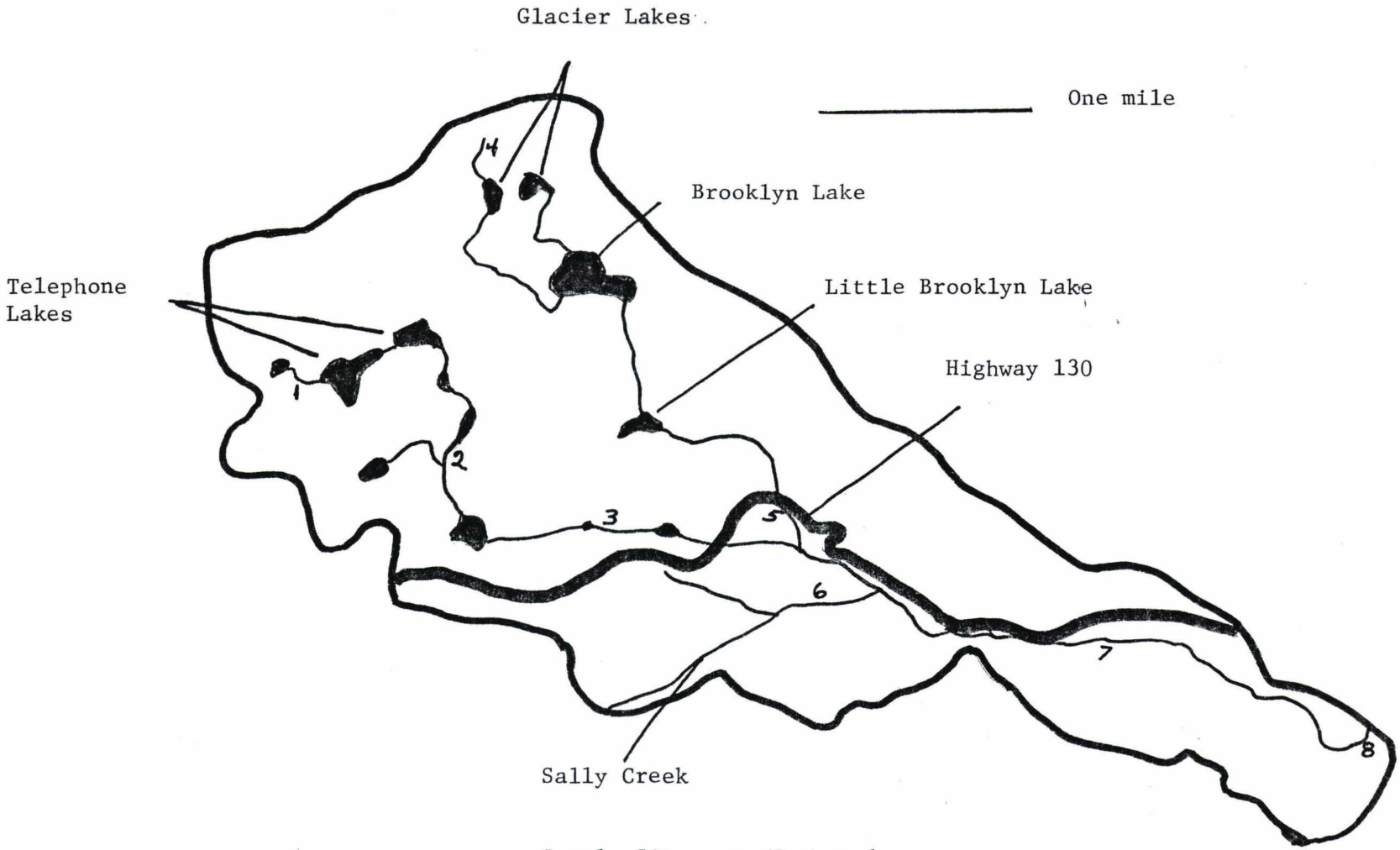
Pool selection The Nash Fork watershed of the Little Laramie River in the Medicine Bow National Forest was used in this study. The pools that were studied were chosen by visual observation based upon the appearance of being representative of pools in the stream and ease of study. The approximate location of the pools is shown in Figure 1.

Sample sites 1,2 and 3 were placed on Telephone Creek. Site 1 was near the top of the drainage at about 10,700 feet in elevation. Site 2 was where the Towner lake road crosses the creek at an elevation of 10,500 feet. Site 3 was the lowest on Telephone creek being located upstream from the Water Resources Research Institute's (WRRI) Mill pond gauging station at an elevation of approximately 10,300 feet.

Sample sites 4,5,6 and 8 were located on the Nash Fork of the Little Laramie River. Site 4 was the highest (elevation 10,800 feet) and was above the glacier lakes. Site 5 was set where highway 130 crosses the Nash Fork at the Brooklyn lake turnoff. Elevation at this point is approximately 10,100 feet. Site 6 was in a meadow above the ski area at an elevation of 9,700 feet. Site 8 was below the ski area at the WRRI gauging station. Elevation here was near 9,200 feet. Site 7 was on Sally creek at an elevation of 10,000 feet.

The user effects in the watershed were as follows: Sally creek is in a natural area. Main effects here should be wildlife and hikers. Telephone creek was affected by some recreation and mainly sheep grazing. Upper Nash Fork creek had campers, hikers, fisherman and some grazing while lower Nash Fork creek was influenced by skiing during the winter.

Sampling design. The eight sample sites were sampled three times each at roughly monthly intervals during July, August and September, 1980. The sample sites above and below the ski are were sampled in May before runoff and site 1 was sampled in October.



Sample Sites are Numbered

Fig. 1. Nash Fork Watershed

Sediment samples were taken initially using sterile Kim Kap test tube closures and then later using 12 ml disposable syringes with the end cut off. The modified syringes were used because it was easier to remove the sample. This was done by depressing the plunger. The collecting of sediment samples was started by placing a protractor parallel to streamflow and setting a transect at a 45 degree angle across the stream. This transect was sampled at 1 to 2 foot intervals depending upon pool size. The core samples were immediately iced for transportation to the laboratory.

After collection of the core samples, water samples were taken simultaneously of the influent and effluent of the pool. Then a rake was drawn along the transect in a width of approximately two feet to suspend the sediment. Simultaneous samples were taken of the influent and effluent as the water cleared. Time intervals between samples varied depending upon visual observation of water clearing. The pools were sampled by starting the first month at the tail of the pool and progressively moving up through the pool each month during the study. No more than a one meter wide transect was distrubed at any one time.

On some occasions the watershed was walked and observed for possible sources and reservoirs of the indicator bacteria. The observed possible reservoirs were then sampled. As a result of these samplings it was determined that moss beds might harbor indicator bacteria. Consequently, core samples were taken through the moss beds and the results compared with numbers in closely associated sediments.

Sample analysis. The water samples and the sediment samples were processed using membrane filtration procedures (1). Millipore brand HC filters were used. The bacterial groups enumerated were fecal coliforms and fecal streptococci. The fecal coliforms were enumerated using MFC medium with incubation

in a waterbath at 44.5 C for 24 hr. The numbers of fecal streptococci were determined on KF agar with incubation at 35C for 48 hr.

Sediment samples were processed by addition of the weighed core to a 99 ml dilution blank. This dilution was vigorously shaken for 60 seconds and then allowed to settle for at least 3 min before filtration. Multiple plates were made from this dilution.

The turbidity of the water samples was determined using a Klett Summerson Photoelectric Colorimeter fitted with the red number 66 filter. Temperature was determined in the field. The pH of the water samples was determined using a Beckman pHistol pH meter. Streamflow was obtained from the Wyoming Water Resources Research Institute.

Data Analysis. The data were analysed using the student t test, analysis of variance and by calculating correlation coefficients.

Results

Initial experiments dealt in part with determining if there were differences in numbers of fecal coliforms between different transects within the same pool and if there were differences between pools. Two pools below the ski area (site 8) were sampled in May 1980. The first pool was sampled with a transect run at the head of the pool and a second transect run at the tail of the pool. The mean fecal coliform values along the transects were 4.9 and 4.1 cells per gram, respectively (Table 1). A student t test gave a value of 0.213 thus indicating that there was no statistically significant difference between the two transects. A second pool was sampled across a transect at the tail of the pool. The mean for the fecal coliforms in this case was 2.6 cells per gram. The student t test value comparing the head of pool one with the tail of pool two was 0.644 while the value comparing the tails of the two pools was 0.551. These values were not statistically different from each other. The second pool was then used for further studies.

The average number of fecal coliforms in the sediments of the Nash Fork watershed was quite low (Table 1). The numbers were generally less than one per gram. There appeared to be an increase in numbers during the summer into September at all sites except above the ski area (site 6). Only the highest sample site on Telephone creek (site 1) was sampled in October before snow made the area inaccessible. No fecal coliforms were found in the sediments in October at site 1. Fecal coliforms appeared to be more numerous in the lower part of the watershed.

The sample site above the ski area had very few fecal coliforms per gram of sediment in May. This was before snow melt and spring runoff. After spring runoff the numbers of fecal coliforms increased from 0.09 per gram to 3.7 per gram. This was a statistically significant increase ($t=3.112$). The numbers of these organisms then decreased throughout the summer. The numbers

Table 1. Fecal coliforms in the sediments of a high mountain stream system

Site	May		July		August		September		October	
	Mean per gram wet weight	Standard deviation	Mean per gram wet weight	Standard deviation	Mean per gram wet weight	Standard deviation	Mean per gram wet weight	Standard deviation	Mean per gram wet weight	Standard deviation
Upper Telephone Creek			0	0	0.14	0.34	0.29	0.69	0	0
Middle Telephone Creek			0	0	0	0	0.27	0.39		
Lower Telephone Creek			0.22	0.58	0.24	0.75	0.42	0.72		
Upper Nash Fork			0	0	0.11	0.22	0.41	0.64		
Lower Nash Fork			0.29	0.94	0.12	0.25	1.52	1.21		
Nash Fork above ski area	0.09	0.14	3.70	3.83	1.50 1.70 1.30	1.81 2.39 1.95	0.71	1.11		
Sally Creek			0.30	0.35	0.24	0.23	0.40	0.36		
Nash Fork below ski area	4.90 4.10 2.60	10.60 8.30 4.70	0.60	1.30	0.40	0.30	1.90	1.70		

in September were significantly lower than in July (t=2.521). Also analysis of variance found the counts at this site in July were significantly higher than any other site (F=9.026) in the watershed.

The sample site below the ski area had the highest numbers of fecal coliforms in the sediments in May that were found in this study. The means ranged from 2.6 to 4.9 per gram. One core sample had 33 cells per gram. These numbers were statistically significantly different from those found above the ski area only at the ninety percent confidence level (t=1.793). This suggests that ski area may have had an influence upon the numbers found. The numbers in the sediment at this site fell to a mean of 0.6 cells per gram in July as runoff was receding. This was significantly lower at the 90 percent confidence level but not at the 95 percent confidence level (t=1.860). This suggests that a scouring of the stream occurred during runoff. The decrease in the numbers of fecal coliforms at this site in July and August was followed by a rise to 1.9 cells per gram of sediments in September. This increase in numbers from August to September was statistically significant at the 95 percent confidence level (t=2.586).

Analysis of variance comparing sites versus days showed that statistically significant differences did occur (F=4.754). Further comparisons in addition to those already discussed, using student t tests found that in August the middle site on Telephone creek (site 2) and lower Nash Fork (site 5) had significantly lower counts in the sediments than the lower sites (sites 6 and 8) in the watershed. The t values were 2.321, 4.444, 2.107 and 2.333, respectively. In September sites 5 and 8 had significantly more fecal coliforms in the sediments than did the three sample sites on Telephone creek. The t values were 2.236, 3.378, 2,683, 2.176, 3.196 and 2.741, respectively. These differences were significant at the 95 percent confidence level.

The fecal streptococci were enumerated at site 1 (upper Telephone creek) in July, September and October, at site 8 (below the ski area) in May and September, at site 5 (lower Nash Fork) only in September and at all other sample sites in July and September. These organisms were more numerous in the sediments than the fecal coliforms (Table 2). Visual examination of the data suggested that these organisms died as the summer progressed. These differences were statistically significant at the 95 percent confidence level in three cases and not significant in three other cases. At sample site 1 the numbers in September were not significantly lower than those in July. In contrast, the numbers in October at this site were significantly lower than those in July. Possibly the other three sites would have yielded similar results had they been sampled in October.

The second part of the project was to disrupt the sediment in the various pools to see if the numbers of the bacteria increased as the turbidity of the water increased. The data for the fecal coliforms were analysed by calculating the correlation coefficient for the relation of numbers to turbidity (Table 3). The numbers were not correlated to the pH of the water samples. There was little correlation between turbidity and numbers in the influent to the studied pools. Generally, there was very little turbidity in the influent samples. Also there was very little fluctuation in the turbidity of the influent samples. Therefore, the following disucssion will deal with the effluent samples. Only one of three sample series in May had a correlation coefficient above 8.000 indicating a poor relationship between turbidity and numbers at this time of year. This poor relationship continued in July as only two of the eight sample sites yielded high correlation coefficients. These were the middle Telephone creek site ($r = 0.996$) and the Sally creek site ($r=0.876$).

Table 2. Fecal streptococci in the sediments of a high mountain stream system

Site	Date	Mean per gram wet weight	Standard deviation	Date	Mean per gram wet weight	Standard deviation	t value	Significant at the 95 percent confidence interval
Upper Telephone Creek	7-16-80	567	662	9-13-80	38	54	1.924	No
	9-13-80	38	54	10-8-80	3	3	1.725	No
	7-16-80	567	662	10-8-80	3	3	2.256	Yes
Middle Telephone Creek	7-14-80	34	73	9-13-80	8	13	1.200	No
Lower Telephone Creek	7-24-80	32	35	9-16-80	6	9	2.900	Yes
Upper Nash Fork	7-21-80	44	24	9-14-80	16	18	2.360	Yes
Lower Nash Fork				9-20-80	6	4		
Nash Fork above ski area	7-22-80	82	52	9-20-80	9	12	4.530	Yes
Sally Creek	7-18-80	65	45	9-16-80	59	99	0.160	No
Nash Fork below ski area	5-16-80	544	719	9-15-80	153	426	1.690	No

Table 3. Effect of sediment disruption upon numbers of fecal coliforms in water

Statistical test	Sample location and number	Site 1 July Numbers per 100 ml	July Turbidity	August Numbers per 100 ml	August Turbidity	September Numbers per 100 ml	September Turbidity	October Numbers per 100 ml	October Turbidity
	A-1[a]	0	3	3	4	15	0	0	0
	A-2	0	3	2.5	4	12.5	0	0	0
	A-3			2.5	3	12.5	0	0.5	0
	A-4			2	4	23	0	0.5	0
	B-1	0	4	21	8	13.5	0	0.5	60
	B-2	0	135	82	930	24	650	2	950
	B-3	0	28	36	75	28	230	0	700
	B-4	0	16	35	53	19	40	0	170
Correlation coefficient	Above	-		0		-		-	
	Below	-		0.980		0.601		0.626	
		Site 2							
	A-1	0	4	0.2	3	.13	0		
	A-2	0	3	0.2	3	3.0	0		
	A-3	0.2	3	0.2	2	2.0	0		
	A-4	0.3	3	0.3	3	3.0	0		
	A-5	0.5	4						
	A-6	0	3						
	B-1	0.5	3	0.2	4	4.3	0		
	B-2	1.5	6	2.0	53	5.0	41		
	B-3	3.5	13	0.8	6	5.0	0		
	B-4	11.7	34	0.2	5	3.5	0		
	B-5	2.8	10						
	B-6	1.0	3						
Correlation coefficient	Above	0.313		0.333		-			
	Below	0.996		0.952		0.513			
		Site 3							
	A-1	1.2	3	2.8	3	1.3	0		
	A-2	0.5	3	1.0	3	2.3	0		
	A-3	0.8	3	1.7	3	0.8	0		
	A-4	1.2	2	2.7	2	1.8	0		
	A-5	0.3	3						
	B-1	0.7	2	1.2	3	0.5	0		
	B-2	1.7	10	4.0	118	4.0	105		
	B-3	0.5	30	1.8	13	2.0	15		
	B-4	1.0	1	1.5	5	2.3	0		
	B-5	1.7	1						

Table 3. continued

Statistical test	Sample location and number	July Numbers per 100 ml	July Turbidity	August Numbers per 100 ml	August Turbidity	September Numbers per 100 ml	September Turbidity	October Numbers per 100 ml	October Turbidity
		Site 3 continued							
Correlation coefficient	Above	0.550		0.505		-			
	Below	0.474		0.992		0.855			
		Site 4							
	A-1	1.5	3	0	4	2.5	0		
	A-2	0	3	0	3	2.0	0		
	A-3			0	3	4.0	0		
	A-4			0	3	2.0	2		
	A-5								
	B-1	1.5	3	0	4	3.5	0		
	B-2	0	23	1.0	30	4.0	64		
	B-3	0	11	0	23	2.5	45		
	B-4	0	4	0	6	3	7		
	B-5	1.0	3						
Correlation coefficient	Above	-		-		0.440			
	Below	0.595		0.744		0.211			
		Site 5							
	A-1	0.5	2	0.3	2	3.0	0		
	A-2	0.7	2	0.3	3	3.0	0		
	A-3	0.3	1	1.7	2	3.0	0		
	A-4	0.8	1	1.3	2	3.0	0		
	A-5	0.3	4						
	A-6	0.3	4						
	B-1	1.0	15	1.0	2	2.0	0		
	B-2	0.5	18	3.0	89	10.0	110		
	B-3	0.7	22	1.0	33	3.0	20		
	B-4	0.7	4	0.5	6	5.0	4		
	B-5	1.2	3						
	B-6	0.7	4						
Correlation coefficient	Above	0.569		0.333		-			
	Below	0.398		0.946		0.923			

Table 3. continued

Statistical test	Sample location and number	Site 6 July Number per 100 ml	July Turbidity	August Number per 100 ml	August Turbidity	September Number per 100 ml	September Turbidity	May Number per 100 ml	May Turbidity
	A-1	26.2	3	5.3	3	2.0	0	0.3	3
	A-2	25.5	4	3.5	3	1.5	0	0.5	3
	A-3	30.7	3	4.7	3	1.0	0	0.5	3
	A-4	32.5	3	4.7	3	2.0	0	0.3	3
	A-5	39.2	3					0.3	1
	B-1	22.7	4	3.2	2	3.0	0	0	3
	B-2	23.3	15	9.3	17	7.0	86	0	8
	B-3	17.7	75	5.0	21	2.5	20	0	5
	B-4	26.5	8	4.3	6	1.5	6	0	3
	B-5	33.7	4					0.3	4
	B-6							0	3
Correlation coefficient	Above	0.537		-		-		0.408	
	Below	0.714		0.621		0.938		0.083	

		Site 7 July Number per 100 ml	July Turbidity	August Number per 100 ml	August Turbidity	September Number per 100 ml	September Turbidity	October Number per 100 ml	October Turbidity
	A-1	1.4	2	0	3	0	0		
	A-2	2.0	3	0.2	3	0.5	0		
	A-3	1.0	4	0.2	3	0.3	0		
	A-4	0.2	4			0	0		
	A-5	1.0	3						
	B-1	0.4	2	0	3	0.3	0		
	B-2	1.6	7	4.0	35	4.0	140		
	B-3	1.8	17	5.0	15	0.5	12		
	B-4	1.0	6	0.7	7	0.5	0		
	B-5	0.6	1						
Correlation coefficient	Above	0.600		-		-			
	Below	0.876		0.712		0.998			

Table 3. continued

Statistical test	Sample location and number	Site 8 July Number per 100 ml	July Turbidity	August Number per 100 ml	August Turbidity	September Number per 100 ml	September Turbidity	October Number per 100 ml	October Turbidity
	A-1	4.6	5	3.0	2	3.5	0		
	A-2	5.2	5	1.8	3	3.3	0		
	A-3	5.2	5	3.3	3	3.3	0		
	A-4	6.0	5	2.5	3	2.0	0		
	A-5	6.5	4						
	A-6	5.9	3						
	B-1	3.8	5	2.5	3	4.5	3		
	B-2	5.5	6	6.5	54	11.0	125		
	B-3	6.3	13	3.8	18	3.0	10		
	B-4	6.2	7	2.7	5	3.5	1		
	B-5	6.2	4						
	B-6	5.5	4						
Correlation coefficient	Above	0.555		0.356		-			
	Below	0.396		0.999		0.977			
		Site 8 Two experiments in May							
	A-1	0.3	12	0	0				
	A-2	0	12	0	3				
	A-3	0	12	0	3				
	A-4	0	2	0.3	3				
	A-5	0	0	0	4				
	B-1	0.5	13	0	5				
	B-2	3.5	38	1.2	33				
	B-3	7.5	170	1.3	28				
	B-4	13.1	20	0	6				
	B-5	0	1	0.7	5				
Correlation coefficient	Above	0.405		0.147					
	Below	0.321		0.867					

a - "A" stands for above, "B" stands for below

The other sites showed much poorer correlation. It might be speculated that this was due to the increased runoff removing more cells from the sediment than it was depositing in the sediment. Additional evidence for this speculation is that as the stream flow decreased into August the number of sites with high correlation coefficients relating turbidity to numbers increased to five (r=0.952 or higher). The sites with poor correlation were the upper Nash Fork site, Sally creek and the above the ski area site. The upper Nash Fork site never showed much relation between turbidity and numbers. In September the lower four sampling sites had correlation coefficients of 0.923 or higher. The lowest site on Telephone creek had an r value of 0.855 while the highest three sites in the watershed had values below 0.602. These results suggest a changing pattern of fecal coliforms in the sediments as time passes.

The fecal streptococci responded to the raking of the stream bottom in a manner similar to that of the fecal coliforms (Table 4). Again no correlation between numbers and turbidity was seen at the highest site on the Nash Fork. Generally, higher correlation coefficients were found in September than in July. In addition, changing patterns with time were also seen for these organisms. For example, at site 3 the correlation coefficient was 0.627 in July and 0.981 in September. In contrast, these values at site 1 were 0.984, 0.974 and 0.626 in July, September, and October, respectively.

Several trips were made walking through the watershed between late July and early September looking for phenomena which might influence the numbers of fecal coliforms in the steam bottoms. Two possibilities were studied further. These were algal growths and moss beds in the streams. Seven different algal samples were taken and processed for the enumeration of fecal coliforms. No fecal coliforms were found in any of the seven samples. This suggests a minimal association between the algae and the fecal coliforms.

Table 4. Effect of sediment disruption upon numbers of fecal streptococci in water

Statistical test	Month	Sample location and number	Site 1 Number per 100 ml	Site 1 Turbidity	Site 2 Number per 100 ml	Site 2 Turbidity	Site 3 Number per 100 ml	Site 3 Turbidity	Site 4 Number per 100 ml	Site 4 Turbidity
		A-1[a]	76	3	75	4	460	3	42	3
		A-2	48	3	114	3	436	3	28	3
		A-3			103	3	224	3		
		A-4			131	3	256	2		
		A-5			91	4	236	3		
	July	A-5			126	3				
		B-1	110	4	137	3	456	2	46	3
		B-2	956	135	117	6	396	10	100	23
		B-3	414	28	129	13	276	30	168	11
		B-4	236	16	1630	34	312	1	58	4
		B-5			192	10	388	1	76	3
		B-6			117	3				
Correlation coefficient		Above	-		0.858		0.321		-	
		Below	0.984		0.946		0.627		0.483	
		A-1	18	0	18	0	38	0	12	4
		A-2	26	0	26	0	46	0	26	3
		A-3	28	0	28	0	36	0	24	3
		A-4	58	0	58	0	40	0	22	3
		A-5								
	September									
		B-1	262	0	262	0	88	0	100	4
		B-2	1635	650	1635	41	640	105	36	30
		B-3	420	230	420	0	68	15	24	23
		B-4	180	40	180	0	110	0	38	6
		B-5								
Correlation coefficient		Above	-		-		-		0.814	
		Below	0.974		0.974		0.981		0.666	

Table 4. Continued

Statistical test	Month	Sample location and number	Site 1 Number per 100 ml	Site 1 Turbidity	Site 2 Number per 100 ml	Site 2 Turbidity	Site 3 Number per 100 ml	Site 3 Turbidity	Site 4 Number per 100 ml	Site 4 Turbidity
		A-1	250	0						
		A-2	0	0						
		A-3	0	0						
		A-4	10	0						
		A-5								
	October									
		B-1	90	60						
		B-2	1000	950						
		B-3	1420	700						
		B-4	450	170						
		B-5								
Correlation coefficient		Above	-							
		Below	0.626							

			Site 5		Site 6		Site 7		Site 8	
		A-1			648	3	74	2	19	12
		A-2			588	4	86	3	15	12
		A-3			572	3	62	4	28	12
		A-4			552	3	70	4	33	2
		A-5					78	3	20	0
	July	A-6								
		B-1			624	4	58	2	45	13
		B-2			648	15	64	7	69	38
		B-3			1036	75	159	17	58	170
		B-4			524	8	179	6	127	20
		B-5			668	4	96	1	22	1
Correlation coefficient		Above			0.032		0.535		0.361	
		Below			0.948		0.548		0.009	

Table 4. Continued

Statistical test	Month	Sample location and number	Site 5 Number per 100 ml	Site 5 Turbidity	Site 6 Number per 100 ml	Site 6 Turbidity	Site 7 Number per 100 ml	Site 7 Turbidity	Site 8 Number per 100 ml	Site 8 Turbidity
		A-1	32	0	34	0	0	0	42	0
		A-2	26	0	32	0	12	0	50	0
		A-3	62	0	26	0	6	0	54	0
		A-4	36	0	30	0	4	0	50	0
	September	A-5								
		B-1	52	0	30	0	0	0	64	3
		B-2	310	110	1,000	86	400	140	560	125
		B-3	240	20	270	20	54	12	46	10
		B-4	224	4	46	6	12	0	96	1
Correlation coefficient		Above	-		-		-		-	
		Below	0.713		0.983		0.999		0.990	

a - "A" stands for above, "B" stands for below.

In contrast, large numbers of fecal coliforms were found to be associated with moss beds in upper Telephone creek. Water extracted from a moss bed in early August when there was no obvious source of pollution in the vicinity contained 400 fecal coliforms per 100 ml. This led to further study of the moss bed.

Core samples taken in late August of sediment and moss beds when sheep were being grazed around the sample site yielded mean fecal coliform values of 2,500 per gram of moss and 570 per gram of sediment (Table 5). The fecal coliforms numbered 400 per 100 ml of free flowing water at this time. The numbers of fecal coliforms were significantly higher at the 90 percent confidence level but not at the 95 percent confidence level in the moss than in the sediment. This was true in both August and September. The difference disappeared in October. Student t tests comparing the numbers of fecal coliforms in the moss in different months showed that the numbers in August with sheep in the vicinity were significantly higher at the 99 percent confidence level than in either September or October (t=3.664 and 3.635, respectively). Comparisons of the numbers in the sediments between months found no significant differences (t=1.887, 1.807 and 0.941).

The data have been analysed by comparing mean values, however the organisms were found to be concentrated in certain areas across the stream. For example, the numbers of fecal coliforms found along a transect taken below the ski area in May were 3.5, 0.2, 0, 0, 2.5, 0, 6.2, 33, 21, 6, 1.7, 0, 0, 3.3, 1.4, 0, 0, 0, 1.6, 1.4. These cores were taken at roughly 18 inch intervals across the stream. These results are representative of both groups of organisms and all sites and times. This is not an unexpected result based upon expected flow patterns through the pools, the experimental design of this project did not allow the size of these areas of concentration to be determined.

Table 5. Comparison of the numbers of fecal coliforms in moss and sediments

Sample location	August			September			October		
	Mean per gram wet weight	Standard deviation	t value	Mean per gram wet weight	Standard deviation	t value	Mean per gram wet weight	Standard deviation	t value
Moss	2500	1500	2.070	5.4	5.5	2.060	25	42	1.050
Sediment	570	720		0.3	0.3		4	10	

Discussion

Data collected in this study showed that indicator bacteria can accumulate in the sediments of mountain streams. Further, it was shown that there was an increase at certain times of the year in the numbers of these bacteria in the water after sediment disruption. The potential then exists for the sediments to remove from or release to the water, cells of the indicator bacteria.

The numbers of the fecal coliforms found in this study were much lower than had been anticipated. The experimental design of this project was to sample the pool in sections as the summer progressed so it wasn't possible to determine the whole load in a pool at any one time. Based upon the numbers found in this study it doesn't appear likely that the sediments could be a major source of these organisms for any length of time. Additional work needs to be done to fully map the entire bottom in several pools to quantify the potential of the sediments as a source of these organisms. Alternatively, maybe studies should be made only comparing the areas of deposition within the pools.

Factors affecting the enumeration of the indicator bacteria which would have been expected to be active in this study include: introduction of cells into the water, death of cells, survival of cells and stream flow. The data obtained in this study can be interpreted to support the following scenario: Fecal coliforms were washed into the stream. The cells then accumulated in moss, sediment or probably other material in the stream. This accumulation was followed by dieaway. A complication was that changes in streamflow tended to spread the organisms out into the watershed. Increases in flow would have scoured the bottom or washed cells off moss beds, etc. and caused suspensions of the cells with subsequent movement down the streams.

This would have caused a reduction in numbers in the more heavily contaminated areas of the watershed. Receding flows would have aided in the settling of these bacteria into new locations thus explaining the increases that were observed later in the summer. Significant sources of pollution should have been evidenced by very large numbers of fecal coliforms at a site such as those seen at the moss bed (2,500 per gram of moss and 570 per gram of sediment) when the samples were taken in the midst of a flock of sheep.

If the above scenario is close to being correct then fecal coliforms added by the ski area disappeared with runoff and new cells from higher in the watershed accumulated at this site during the summer. Runoff deposited cells in the flat above the ski area which were then lost during the summer. The second site on the Nash Fork (site 5) accumulated significant numbers of fecal coliforms. The only pollution event easily identified was due to grazing of sheep and this effect disappeared rather rapidly.

Additional work should be centered on proving or disproving the presented scenario. The length of survival time of the fecal coliforms in high mountain watersheds needs to be elucidated. Places in the streams where cells may be deposited and the relative importance of these places need to be determined. Natural factors which cause or aid in the release of the deposited cells need to be identified.

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Appendix 1. Fecal coliforms in sediment samples, viable cells per gram

Sample number	Site 1 Date 7-16-80	8-18-80	9-13-80	10-8-80
1	0	0	0	0
2	0	0	0	0
3	0	0.9	0	0
4	0	0	1.7	0
5	0	0	0	0
6	0	0	0	0
7	0	0		0
8	0			

Sample number	Site 2 Date 7-14-80	8-18-80	9-13-80
1	0	0	0
2	0	0	0.8
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	1.2
8	0	0	0.4
9	0	0	0
10	0	0	0.4
11	0	0	0.4
12	0	0	0
13	0		
14	0		
15	0		

	Site 3 Date 7-24-80	8-18-80	9-16-80
1	0	0	0.3
2	0	0	0.4
3	0	0	0
4	0	0	0.6
5	0	0	0.3
6	0.2	0	0.9
7	0	0	2.5
8	0.2	0	0
9	0	2.9	0
10	2.4	0	0
11	0.9	0	0
12	0	0	0
13	0	0.5	
14	0	0	
15	0	0	
16	0		
17	0.2		
18	0		

	Site 4 Date 7-21-80	8-19-80	9-14-80
1	0	0	0.9
2	0	0	1.5
3	0	0.5	0
4	0	0	0
5	0	0	0
6	0		0
7	0		

Appendix 1. continued

Sample number	Site 5 Date 7-7-80	8-19-80	9-2-80
1	0	0.6	1.0
2	0	0.7	2.8
3	0	0	2.1
4	0	0	0.3
5	0	0	2.9
6	0	0	0.7
7	0.3	0	0
8	0	0	0.8
9	0	0	3.1
10	0	0	
11	0	0	
12	0	0	
13	0		
14	0.2		
15	3.8		
16	0.2		

Sample number	Site 6 Date 5-26-80	7-22-80	8-3-80	8-4-80	8-19-80	9-20-80
1	0	5.1	1.2	8.0	0	0
2	0	14.2	0.6	3.0	0	3.4
3	0	2.9	1.7	0.8	1.1	0
4	0.4	3.2	2.0	0	0	0
5	0	2.1	5.2	1.6	1.7	0.7
6	0.2	0.6	0	0	0	0
7	0	0.9	0	1.5	4.4	0
8	0	8.5	0.4	0.6	0.3	0.7
9	0	3.0	4.1	0.8	5.3	2.2
10	0.3	0.6	0	0.5	0.4	0.7
11	0	0.7				0
12		5.9				
13		0.5				
14		3.3				

	Site 7 Date 7-18-80	8-18-80	9-16-80
1	0.5	0	0
2	0.4	0.3	0.7
3	0.9	0	0
4	0	0.4	0.6
5	0	0.5	0.7
6	0		
7	0		
8	0		
9	0.8		
10	0.3		

	Site 8 Date 5-16-80	5-16-80	5-22-80	7-9-80	8-19-80	9-15-80
1	0	3.5	0.8	0.2	0.4	1.1
2	31.0	0.2	2.3	0.6	0.5	0.4
3	0.4	0	0.7	0.2	0	0.9
4	1.0	0	15.6	0	0.4	3.8
5	1.3	2.5	5.9	0	0.8	0
6	0.3	0	0	0	0	1.4
7	0.9	6.2	0	0	0.7	1.6
8	4.6	33.0	0	5.6	0	4.4
9		21.0	2.8	0	0.5	4.2
10		6.0	0.5	0.3		3.6
11		1.7	0	0		0
12		0		1.0		
13		0		0.3		
14		3.3		0.3		
15		1.4		0		
16		0		0		
17		0		0.2		
18		0		2.3		
19		1.6		0		
20		1.4		0.2		

Appendix 2. Fecal streptococci in sediment samples[a]

Sample number	Site 1 Date 7-16-80	Site 1 Date 9-13-80	Site 1 Date 10-8-80
1	70	15	0
2	15	18	4
3	785	41	7
4	888	145	0
5	75	5	0
6	1960	5	6
7	130		2
8	617		

Sample number	Site 2 Date 7-14-80	Site 2 Date 9-13-80
1	0	5
2	9	0
3	29	0
4	22	45
5	20	4
6	0	3
7	18	0
8	291	7
9	54	4
10	20	18
11	0	4
12	0	3
13	41	
14	0	
15	0	

Sample number	Site 3 Date 7-24-80	Site 3 Date 9-16-80
1	87	4
2	27	4
3	13	0
4	6	6
5	6	0
6	21	4
7	32	9
8	124	0
9	20	6
10	7	0
11	9	6
12	11	33
13	79	
14	74	
15	2	
16	12	
17	27	
18	27	

Sample number	Site 4 Date 7-21-80	Site 4 Date 9-14-80
1	51	46
2	23	5
3	44	3
4	90	0
5	19	13
6	47	28
7	33	

Sample number	Site 5 Date 9-20-80
1	10
2	3
3	3
4	7
5	5
6	9
7	14
8	0
9	5

Sample number	Site 6 Date 7-22-80	Site 6 Date 9-20-80
1	61	0
2	200	33
3	52	11
4	113	5
5	42	0
6	37	0
7	38	9
8	141	5
9	85	33
10	32	3
11	72	0
12	162	
13	56	
14	57	

Sample number	Site 7 Date 7-18-80	Site 7 Date 9-16-80
1	132	4
2	82	0
3	87	19
4	47	234
5	0	37
6	13	
7	68	
8	19	
9	42	
10	125	

Sample number	Site 8 Date 5-16-80	Site 8 Date 9-15-80
1	35	61
2	10	12
3	16	20
4	824	1400
5	374	0
6	55	32
7	174	22
8	1700	44
9	2000	19
10	2400	5
11	115	27
12	17	
13	367	
14	293	
15	611	
16	785	
17	44	
18	25	
19	117	
20	866	

a - values presented are viable cells per one gram of sediment.

Appendix 3. Temperature and streamflow

Date	Site	Temperature	Streamflow in cubic feet per second
5-16-80	8	2	2.74
5-22-80	8	1	9.97
5-26-80	6	0	———
7- 7-80	5	11	20.18
7- 9-80	8	10	14.98
7-14-80	2	11	14.53
7-16-80	1	6	———
7-18-80	7	7	1.28
7-21-80	4	5	———
7-22-80	6	10	9.00
7-24-80	3	15	5.62
8-18-80	7	7	0.32
	3	10	2.90
	2	10	2.58
	1	8	———
8-19-80	6	9	2.04
	8	9	2.04
	5	8	2.90
	4	—	———
9-13-80	1	7	———
	2	7	3.02
9-14-80	4	6	———
9-15-80	8	8	1.94
9-16-80	3	9	2.02
	7	6	0.23
9-20-80	5	3	2.36
	6	5	1.18
10-8-80	1	10	———

Appendix 4. pH values of water samples.

Month	Water sample	Site number 1	2	3	4	5	6	7	8
	A-1[a]						7.0		7.2
	A-2						7.0		7.3
	A-3						7.0		7.2
	A-4						7.0		7.3
	A-5						7.0		7.3
May	A-6								
	B-1						7.0		7.1
	B-2						7.0		7.1
	B-3						7.0		7.2
	B-4						7.0		7.1
	B-5						7.0		7.1
	B-6						7.0		
	A-1	7.4	7.4	7.2	7.4	7.6	7.5	7.6	7.4
	A-2	7.4	7.4	7.2	7.6	7.4	7.5	7.6	7.2
	A-3		7.4	7.3		7.6	7.6	7.6	7.4
	A-4		7.4	7.3		7.5	7.7	7.5	7.4
	A-5		7.4	7.3		7.5	7.5	7.5	7.4
July	A-6		7.4			7.6			7.3
	B-1	7.4	7.4	7.4	7.6	7.6	7.4	7.6	7.5
	B-2	7.1	7.4	7.5	7.7	7.5	7.4	7.6	7.4
	B-3	7.2	7.3	7.4	7.5	7.6	7.4	7.6	7.4
	B-4	7.4	7.4	7.5	7.6	7.5	7.4	7.6	7.4
	B-5		7.4	7.5	7.7	7.6	7.4	7.6	7.4
	B-6		7.4			7.6		7.6	7.4
	A-1	7.2	7.2	7.2	7.9	7.4	7.4	6.8	7.4
	A-2	7.2	7.4	7.0	7.6	7.0	7.4	7.0	7.2
	A-3	7.2	7.4	6.8	7.8	7.2	7.4	7.0	7.2
August	A-4	7.2	7.4	6.8	7.6	7.1	7.4		7.1
	B-1	7.2	6.8	7.2	7.2	7.3	7.4	7.0	7.2
	B-2	7.4	6.8	7.2	7.0	7.2	7.4	7.0	7.2
	B-3	7.2	6.8	7.0	7.0	7.3	7.4	7.0	7.2
	B-4	7.4	7.2	7.2	7.0	7.2	7.3	7.0	7.0

Appendix 4 continued.

Month	Water sample	Site number 1	2	3	4	5	6	7	8
	A-1	6.6	6.8	6.8	6.8	7.0	6.8	6.8	6.8
	A-2	6.6	7.0	7.0	6.8	7.0	6.8	6.8	6.8
	A-3	6.6	6.8	7.2	6.8	7.0	7.2	7.2	6.8
September	A-4	6.8	6.8	6.8	6.8	7.0	6.8	6.8	6.8
	B-1	6.8	6.8	7.0	6.8	6.8	7.3	6.8	6.8
	B-2	6.8	6.8	6.8	6.6	6.8	7.2	6.7	6.8
	B-3	6.8	6.8	7.0	6.6	6.9	7.2	7.2	6.8
	B-4	6.8	7.0	7.2	6.6	6.7	7.2	7.4	6.8
	A-1	6.6							
	A-2	6.6							
	A-3	6.6							
October	A-4	6.6							
	B-1	6.6							
	B-2	6.6							
	B-3	6.6							
	B-4	6.6							

a -"A" stands for above and "B" stands for below.